PB-230 836

ESTABLISHMENT OF NATIONAL EMISSION STANDARDS FOR STATIONARY SOURCES. VOLUME VI. PORTLAND CEMENT MANUFACTURING PLANTS

H. L. Hamilton, Jr., et al

Research Triangle Institute
Durham, North Carolina

30 September 1970

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 230 836

ESTABLISHMENT OF NATIONAL EMISSION STANDARDS FOR STATIONARY SOURCES

Volume VI Portland Cement Manufacturing Plants

Contract No. CPA 70-164
Task Order No. 2

FINAL REPORT

September 30, 1970

Prepared for

National Air Pollution Control Administration
411 West Chapel Hill Street
Durham, North Carolina

by

Research Triangle Institute

and

PEDCo Environmental Specialists, Incorporated

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

TABLE OF CONTENTS

		Page No.
1.0	INDUSTRY CHARACTERISTICS	1
2.0	TYPE OF ATMOSPHERIC EMISSIONS	3
3.0	DESCRIPTION OF PROCESSES	6
	3.1 Quarrying and Crushing	6
	3.2 Grinding	6
	3.3 Heating and Burning	7
	3.4 Final Grinding	9
4.0	EMISSION LEVELS	10
	4.1 Dry Process	13
	4.2 Wet Process	14
5.0	AIR POLLUTION CONTROL REGULATIONS FOR EMISSIONS FROM CEMENT PLANTS	16
6.0	CONTROL TECHNOLOGY	30
	6.1 Cyclones	30
	6.2 Electrostatic Precipitators	31
	6.3 Glass-Fabric Baghouses	35
7.0	DESCRIPTION OF PLANT UTILIZING BEST TECHNOLOGY	39
	7.1 Raw-Feed Blending	41
	7.2 Kiln and Cooler Control	42
	7.3 Clinker Handling and Storage	43
	7.4 Finish Grinding	43
	7.5 Storage-Packing-Loading	43
	7.6 Dust Collection, Miscellaneous	44
	REFERENCES	46

1.0 INDUSTRY CHARACTERISTICS

The Portland cement manufacturing industry in the United States began over 100 years ago in the Lehigh Valley of Pennsylvania.[1] This region contains the right amount of raw materials to produce a quality product for a large metropolitan market. There are presently 12 cement plants in this area with a capacity of over 23,000,000 barrels annually.[2]

According to the U. S. Bureau of Mines, there are over 180 cement manufacturing plants now in operation in the United States. The estimated shipments from these plants in 1969 were about 407 million barrels, an increase of about 9.6 million barrels or 2.3% over the 1968 total of 397.4 million barrels.[3] The official capacity of the plants was approximately 518 million barrels[3] which shows that only 78.6% of the available capacity was used.

The growth rate of the cement industry has increased regularly since World War II. The amount of productive capacity installed in 1969 was up sharply from 1968 but was still the second lowest since 1961.[3] Producers are still uncertain about long-range prospects for the industry but generally are optimistic. However, for the immediate future, particularly 1970, most producers are pessimistic. One national producer projected a 10% decrease in volume for the industry for the first 6 months of 1970, and 4% for the second half, averaging 6-7% for the year.[3] However, U. S. Bureau of Mines figures show shipments for the first three months of 1970 totaled 62,918,000 barrels which was 3.6% below the first quarter of 1969 (65.3 million barrels) but 4% over the first quarter of 1967.[4]

In 1969 about 19.1 million barrels of added capacity was added to the

cement industry in this country.[3] Plant and equipment shutdowns, however, at various locations probably reduced the actual capacity added to the industry to be less than 10 million barrels.[3] Estimates show that installations totaling approximately 12.4 million barrels of cement capacity may be completed in 1970.[3]

2.0 TYPE OF ATMOSPHERIC EMISSIONS

Portland cement is made from a blended mixture of various types of calcareous and argillaceous materials such as chalk, clay, limestone, and shale. These are ground into a very fine dust, are heated in a kiln, decarbonated and eventually sintered to clinkers at very high temperatures (~2600-2800°F). A certain amount of dust, which depends largely on the friability of the raw materials, is produced in the kiln. The dust becomes suspended in the gases and comes out of the kiln in this form. Thus, the primary source of dust in a cement plant is the kiln operation.

The hot clinker that forms in the kiln is cooled in a "clinker cooler" and ground with a proportion of gypsum to form the end product Portland cement. Both of these operations as well as the conveying and packaging operations are sources of dust. Other sources of dust include the initial quarrying operation and movement of the raw materials.

In a cement plant the initial materials are dust and the end product is a fine dust. It is not surprising, therefore, that dust is the major atmospheric emission from a cement manufacturing operation. Dust generated in a dry-process kiln may vary from 1 to 25% expressed in terms of the finished cement and from 1 to 33% from the wet process.[5] To express this differently, an 8000 bbl/day, or 2,900,000 bbl/yr dry kiln would generate from 32,000 to 752,000 pounds of dust per day, or 1330 to 31,300 lbs/hr. For a wet process, the equivalent figures would be from 1330 to 41,300 lbs/hr. Thus, it can be seen that a major dust problem exists if there are no controls.

In order to assess the extent of the problem in the Lehigh Valley, surveys by nationally known air-pollution experts were made in the region's

municipalities in 1956.[1] One report stated that a number of tests indicated that more than 4000 tons of dust per square mile fell in every part of the community in a year's time. Another report stated that as much as 1200 tons per square mile per month fell at check points in a residential area near a cement-manufacturing plant.

The emissions from a clinker cooler are much larger in size than those from other operations in a cement plant. In fact they may be as large as 600-1000 microns while typical dust from the kilns are from 45 microns down. One plant in the Lehigh Valley that vented its clinker cooler to the atmosphere from a chimney a few feet above the roof had a roof cave in from the weight of the clinker emissions.[2]

The "Blobbing" phenomenon in which the dust in the issuing gases agglomerates to form flakes and spheres which precipitate out of the atmosphere and cause splashes has been noted since electro-filters were introduced in the cement plants in Great Britain.[6] However, it is noted that this phenomenon is not peculiar to electro-filters but has also been found with cyclones.

Other types of pollution from a cement plant include gaseous emissions from the combustion of fuel in the kiln. Most of the sulfur dioxide formed from the sulfur in the fuel is recovered because it combines with the alkalies and also with the lime when the alkali fume is low.[5] One company in Canada tested their kiln exit gases for SO_2 and found a concentration ranging from 6 to 39 parts per million when a 2.8 percent sulfur coal was burned.[5] Nitrogen oxides can also form at kiln temperatures of 2600 to 3000°F and may be of concern in areas that have photochemical-type air pollution.[5] No data are available at this time on the amount of nitrogen

municipalities in 1956.[1] One report stated that a number of tests indicated that more than 4000 tons of dust per square mile fell in every part of the community in a year's time. Another report stated that as much as 1200 tons per square mile per month fell at check points in a residential area near a cement-manufacturing plant.

The emissions from a clinker cooler are much larger in size than those from other operations in a cement plant. In fact they may be as large as 600-1000 microns while typical dust from the kilns are from 45 microns down. One plant in the Lehigh Valley that vented its clinker cooler to the atmosphere from a chimney a few feet above the roof had a roof cave in from the weight of the clinker emissions.[2]

The "Blobbing" phenomenon in which the dust in the issuing gases agglomerates to form flakes and spheres which precipitate out of the atmosphere and cause splashes has been noted since electro-filters were introduced in the cement plants in Great Britain.[6] However, it is noted that this phenomenon is not peculiar to electro-filters but has also been found with cyclones.

Other types of pollution from a cement plant include gaseous emissions from the combustion of fuel in the kiln. Most of the sulfur dioxide formed from the sulfur in the fuel is recovered because it combines with the alkalies and also with the lime when the alkali fume is low.[5] One company in Canada tested their kiln exit gases for SO_2 and found a concentration ranging from 6 to 39 parts per million when a 2.8 percent sulfur coal was burned.[5] Nitrogen oxides can also form at kiln temperatures of 2600 to 3000°F and may be of concern in areas that have photochemical-type air pollution.[5] No data are available at this time on the amount of nitrogen

oxides or polysulfides which are produced. The major problem, however, is known to be the dust problem and this is the one that is receiving all the attention and effort of cement manufacturers.

3.0 DESCRIPTION OF PROCESSES

Portland cement is made from an accurately blended mixture of finely ground calcareous (lime component) and argillaceous (alumina component) materials. The four major steps for producing Portland cement are: (1) obtaining raw materials and reducing their size (blasting, crushing, grinding), (2) grinding, blending and homogenization of these materials to obtain desired composition and uniformity, (3) heating to liberate carbon dioxide and burning to form clinkers, (4) grinding or fine pulverization of these clinkers with addition of gypsum. Each of these steps will be discussed in this section.

3.1 Quarrying and Crushing

The raw materials are normally blasted and removed by large machinery. Sometimes as much as 400,000 tons of rock are dislodged in a single blast. This rock is then fed into large crushers that change them from sizes such as grand pianos to golf or baseball size. The crushers normally used may be classified as gyratory, jaw, or roll crushers, hammer mills, and impact mills. This operation may be performed at the quarry.

3.2 Grinding

The grinding operation, as the name implies, changes the crusher product into a fine dust. Two different grinding processes, dry and wet, are used in modern cement plants. At the present time in the United States, the manufacture of cement is divided between these processes according to Table 1.

Table 1. Portland Cement Production by Process.[8]

	Wet Process	Dry Process
Number of Plants	60%	40%
Plant Capacity	58%	42%
Number of Kilns	41.5%	58.5%

3.2.1 Dry Process

In the dry process, the raw materials are dried to approximately 1% moisture before the grinding operation. The materials are usually 2 to 2½ in. in diameter and are dried in rotating cylindrical dryers before grinding. The grinding is usually accomplished in two stages. For the first stage, vertical, roller, ball-race, or ball mills are used. For the second stage, tube mills are normally used. Some compartment mills which combine ball and tube mills are used for the second stage. These mills may be operated in closed circuit with air separators that separate the particles into coarse and fine fractions so that the coarse ones may be reground. The product of the grinding operation is a powder, 75% to 90% of which will pass through a 200-mesh sieve.

3.2.2 Wet Process

In wet-process grinding, ball, tube, and compartment mills similar to those used in the dry process are used. Water or clay slip is added at the feed end with properly proportioned amounts of limestone and other components. Grinding may be done in single stage mills or two stages as in the dry process.

In some wet process mills the grinding of the different materials is done in separate slurries and proportioned later. In others the materials are proportioned before adding the water and grinding. The raw-materials slurry leaving the grinding operation may contain as much as 33% moisture.[1]

At some locations the quarry-run materials contain excess carbon and/or silica which is removed by froth flotation.

3.3 Heating and Burning

The most important part of any Portland cement plant is the kiln in

which the proportioned dust from the grinding operation is heated to liberate carbon dioxide and fused to form clinkers.

The original kilns used in this industry were vertical kilns or shaft kilns.[8] These are no longer used in the United States and Canada but still have widespread use in Europe. They are attractive from a fuel economy viewpoint but require considerably more labor.

The modern rotary kilns are quite large and consist of a welded or riveted steel cylinder which may vary from 6 ft in diameter and 60 ft long (now rare)[8] to 25 feet in diameter and 760 feet long.[9]

The cylinders ride on steel tires and rubber supports, are inclined a few degrees, and rotate at 50 to 90 revolutions per hour. Kiln feed or raw mix ("slurry" in wet-process kiln and "raw-meal" in dry-process kiln) is fed into the upper end, flows slowly through the kiln in a matter of hours, and leaves the discharge end as clinker. During passage of the feed down the kiln several reactions take place at different temperatures. These may be classified as follows[7]: (1) water evaporation, (2) calcination of limestone and magnesite, (3) sintering of part of the material, and (4) interaction to form silicates or aluminates.

Heat is supplied at the discharge end by combustion of fuels such as coal, oil, or natural gas. At one time most of the plants used coal but many have changed in recent years to other fuels. Combustion gases pass through the kiln in a counterflow pattern and leave the kiln through the feed (upper) end at temperatures of 600° to 1600°F depending on the kiln length and process used.

Wet-process kilns are generally longer than dry-process kilns since ¼ to 1/5 of the length must be used for water evaporation. These kilns

also have elaborate heat exchangers consisting of heavy chains suspended in loops or curtains inside the kilns. These chains are arranged so that they not only lift the slurry into the path of the hot gases but also convey the raw material to the burning zone.

Hot clinker from the rotary kilns goes directly to clinker coolers which both reduce the temperature of the clinker before it is ground and recover heat for reuse inside the kiln as preheated combustion air. Various types of clinker coolers which permit blasts of cooling air to pass through a slowly moving bed of hot clinkers may be used.

3.4 Final Grinding

The cooled clinker passes to a final grinding mill similar to those discussed in the dry-process grinding operation. It is ground with 4 to 6% gypsum to a powder so fine that most if it will pass through a sieve that will hold water. The purpose of the gypsum is to cause the concrete formed with cement, water and aggregate to remain workable for several hours. Without the gypsum the material would probably set before it was properly finished.

4.0 EMISSION LEVELS

As stated earlier, particulates are the primary air pollution problem associated with Portland cement manufacturing plants. More general type data are available which show the actual deposition of dust over an area adjacent to or near cement plants, suspended particulate levels in the surrounding air, or concentrations of dust leaving the kiln or entering the dust collection system than data which show actual stack emissions.

The dust problems associated with the 12 cement plants in the Lehigh Valley in Pennsylvania are unique for this industry because of the heavy concentration of these plants in that area. The dust emissions for 1956 which were reported earlier as more than 4000 tons of dust per square mile per year in every part of the community to as high as 1200 tons/sq. mile per month adjacent to a cement plant have been reduced considerably. Table 2 shows the dustfull for several years in the town of Northampton, which is in the center of the cement belt. Of the 12 plants, 9 are dry-process plants and 3 are wet-process.

Table 2. Average Dustfall in Northampton, Pa. in 30 Day Period.[11]

Date	Concentration tons/sq. mile	g/m^2
1958	201	70
1967	61	21
1968	44	15.4

These figures show that the problem has been reduced considerably but the 1968 figures still slightly exceed the limits of 43 tons/sq. mile or 15 g/m^2 specified by Pennsylvania in 1967 in its Ambient Air Quality Criteria.[11]

The suspended particulate concentration in this Lehigh Valley area averaged 240 $\mu g/m^3$ and was as high as 1.084 $\mu g/m^3$ during 24-hour samplings from March to June of 1964.[11] Approximately 83 percent of these particulates were found to be emitted from cement plants.

In the past 11 years, approximately $22 million has been spent by these Lehigh Valley cement plants to control particulate emissions.[11] Because of this, dustfall averages in the cement-producing regions of the Lehigh Valley have declined more than 75 percent. The only type of complaints that must still be resolved relating to cement dust is that paint finishes on automobiles, homes, and buildings exhibit rapid damage. Between 1958 and 1960, when the Lehigh Valley Air Pollution Control District included only 6 of its present 12 cooperating municipalities, this agency received an average of 10 complaints a day relating to cement dust or plants.[11]

The Missouri Portland Cement Company's plant is located in a residential area of St. Louis County, Missouri, about 9 miles upstream from downtown St. Louis. The plant is in the town of Riverview Gardens with a 1960 population of 3,706.[11] Bellefontaine--Neighbors, located one-half mile from the plant had a 1960 population of 13,650. Over 125 complaints have been received by the St. Louis County Health Department since 1963 and a petition from over 275 residents of Bellefontaine--Neighbors requesting improvement of air quality was submitted in 1968.[11]

The St. Louis County Health Department has measured dustfall at a sampling station near this plant for several years. The values recorded at this sampling station are shown in Table 3.

Table 3. Dustfall Measurements Near Missouri Portlant Cement Company Plant by October 1968.[11]

	Concentration	
	tons/sq. mile/month	grams/sq. meter/month
Average	30	10.5
Maximum	60	21

Both values exceeded the ambient air quality standard of 5.25 g/m^2-mo (15 tons/sq. mile-month) (three-month average) which was adopted for the St. Louis metropolitan area by St. Louis County and the Air Conservation Commission of the State.

Suspended particulates during the three years ending in August 1968 averaged 104 $\mu g/m^3$ and the highest daily levels were about three times this value.[11] The ambient air quality standard adopted by the State and county is 75 $\mu g/m^3$.

Actual emission levels, measured in the latter part of 1968, ranged from 150 to 510 pounds/hour, with an average of 320 pounds/hour.[11] According to Mr. Bruce E. Kester, Director of Research for Missouri Portland, these figures were based on 33 successive tests.[12] Today, Mr. Kester states that the emissions are approximately 1/10 of these values since a new electrostatic precipitator has been installed in parallel with the previously existing one. The plant is now meeting the St. Louis County Air Pollution Control Code which limits a plant the size of Missouri Portland's to slightly less than 60 pounds/hour of particulate emissions.

It is quite difficult and impractical to determine average particulate emission rates from kiln operations because no two cement plants are exactly alike. Kiln sizes, methods of blending raw materials, firing rates,

types of clinker coolers, whether the process is wet or dry all are characteristics that affect emission rates. The method in which gases are liberated during calcination of limestone and the composition of kiln feed also affect the emission rates.

The emission data given in Reference 5 which were obtained from different cement plant officials seem to be the most authoritative of any information. Even today most plant officials state that the data given therein are the best data available. A summary of these data are presented and discussed in the following paragraphs.

4.1 Dry Process

Data presented in Reference 5 for 14 dry-process kilns show that dust concentration leaving the kiln and entering the dust collection system ranged from 1.1 to 12.4 grains per cubic foot. The arithmetic average for all tests was 6.4 grains per cubic foot. The dust concentrations did not seem to be a function of different types of dry-process kilns.

The amount of dust entering the dust collectors from dry-process kilns ranged from 1 to 29 percent of the finished cement weight, or from 4 to 94 pounds per barrel (standard barrel 4 cubic feet, or 376 pounds). The average for nine dry-process kilns was 11.3 percent of the finished cement weight. One plant had .705 percent and one 29.3 percent of the finished weight. Also the efficiency of the dust collection systems varied considerably for the plants reporting with the low being 70.2% and the high being 99.8%. One report stated that the average weight of dust collected from kiln exit gases was 48.1 pounds per barrel of clinker.[13] This would be equivalent to 46 pounds of dust per barrel of cement if 5% gypsum were used.

The dust actually emitted to the atmosphere from the 14 dry-process plants reported in Reference 5 varied from 326 pounds/day for a 2900 bbl/day plant to 67,900 lbs/day for a 5260 bbl/day plant. The dust emissions ranged from .03% to 3.43% when compared to the finished product. For the largest plant reported with a production rate of 9580 bbl/day, the dust emissions to the atmosphere were 1264 lbs/day, or 53 lbs/hr. This plant had a dust collection efficiency of 99.8 percent which was the highest reported and probably the maximum obtainable from a practical viewpoint. However, even with this high collection efficiency, the emission rate exceeds that specified in the Los Angeles County Air Pollution Code which is the most stringent in this country for particulates. Several other areas have Air Pollution Codes based on the Los Angeles Code which limits the particulates to 40 lbs/hr regardless of the plant size. In fact all of the dry-process plants reported in Reference 5 except the one plant with 326 lbs/day exceeded these stringent regulations. The arithmetic average for the 14 reporting plants was 11,400 lbs/day, or 475 lbs/hr. Of course, the one plant with emissions of 67,900 lbs/day increased this average considerably. However, even after removing this one plant, the average for the 13 remaining plants is still 7000 lbs/day, or 292 lbs/hr.

4.2 Wet Process

Data presented in Reference 5 for 22 wet-process kilns show that dust concentrations leaving the kilns and entering the dust collection systems ranged from 0.995 to 13.51 grains per cubic foot. The arithmetic average for all tests was 7.5 grains per cubic foot. As for the dry-process kilns, no apparent difference was noted for different length kilns.

The amount of dust entering the dust collector from the wet-process

kilns ranged from 1 to 33 percent of the finished cement weight, or from 4 to 124 pounds per barrel. The arithmetic average for 13 wet-process kilns was 10.1 percent of the finished cement weight. Kannewarf and Clausen[13] stated that the average weight of dust collected per barrel of clinker was 39.8 pounds. This would be equivalent to 38 pounds of dust per barrel of finished cement.

The dust actually emitted to the atmosphere from the 22 wet-process plants varied from 289 lbs/day to 14,000 lbs/day. The emissions ranged from .0175% to 1.21% when compared to the finished cement. Only 4 of these 22 reporting plants had dust emissions that would meet the Los Angeles Air Pollution Code of 40 lbs/hr. The arithmetic average of dust emissions to the atmosphere was 3630 lbs/day or 151 lbs/hr. Removing the two plants with 14,000 and 11,400 lbs/day lowers this average to 2720 lbs/day, or 114 lbs/hr which is still considerably above the Los Angeles Code. For all of these figures the minimum dust collection efficiency was 92.4% and the maximum was 99.74%. For the four plants which would meet the LA regulation, the minimum collection efficiency was 99.49%.

5.0 AIR POLLUTION CONTROL REGULATIONS FOR EMISSIONS FROM CEMENT PLANTS

About 20 years ago, the Los Angeles County Air Pollution Control District (LACAPCD) developed the process-weight regulation which limited total particulate emission rates from industrial processes as a function of the process-weight rate.[14] Process weight is generally the total weight of all raw materials, including solid fuel but not gases, which are introduced into a process. This method removed dilution as a factor in meeting emission standards.

The Los Angeles regulation was derived after studying the many metallurgical processes located there. The basis for degree of control was determined by analyzing well-controlled and well-operated plants. This regulation demonstrated that many types of industries regardless of the type, can meet the regulation. However, no cement plants are located in Los Angeles County and would have real trouble meeting this regulation. The maximum-allowable emission limit for particulates was set at 40 pounds per hour regardless of the process weight.

In 1959, the Bay Area Air Pollution Control District in San Francisco (BAAPCD) developed another process-weight regulation based on well-controlled industries there.[14] This included some mineral-based processes not found in Los Angeles County. Thus, the Bay Area Regulation is similar to the Los Angeles Regulation in the lower range allowing 12 lbs/hr of emission for 10,000 lbs/hr process weight as compared to 10.0 lbs/hr in Los Angeles, 25.2 lbs/hr as compared to 22.22 lbs/hr for 30,000 lbs hr is identical at 40.0 lbs/hr for 60,000 lbs/hr but increases to a maximum of 92.7 lbs/hr for a process weight of 6 million pounds per hour. This appears to be a more reasonable regulation for a wider range of sources and, therefore, has been

more widely accepted. Although other agencies have developed process-weight regulations, the Los Angeles and Bay Area regulations are the only ones widely accepted. In fact, many states have their own regulations, but they are usually based on one of these two regulations.

The cement industry has trouble meeting even the Bay Area regulation in large plants because relatively difficult technical problems with resulting economic hardship. For instance, in the Ideal Cement Company Plant in Seattle which is considered by all cement plant officials and experts as the best controlled cement plant overall from an air pollution viewpoint invested $4,000,000 in air pollution control equipment out of a total plant investment of approximately $30,000,000.[15]

The State of Pennsylvania has developed a regulation with varying emission limits based on the pollution potential of the source. This regulation has several sets of emission limits which are applicable to different parts of the state. It is designed to require greater collection efficiency for those operations that would discharge large quantities of pollutants. Although the cement industry contributes large amounts of particulates, the Pennsylvania regulation is much less stringent for this type of operation than even the Bay Area regulation. For example, for a large cement plant with a production rate of 9,580 bbl/day, the Bay Area regulation limits the emission rate to 54.6 lbs/hr while the Pennsylvania regulation allows 183 lbs/hr[14]. Similarly for a 3,900 bbl/day cement plant, the Bay Area regulation specifies 45.6 lbs/day and the Pennsylvania one 62 lbs/day.

Most cement plant officials feel that the Los Angeles regulation that stops at 40 lbs/hr emission regardless of the plant size is not realistic for cement plants. Several expressed the opinion that the technology is

not available at this time to meet this regulation.[16] However, one plant official stated that the technology does exist, but it would be very, very costly to meet this regulation.[12] In fact, he further stated that if a system were designed to meet the 40 lbs/hr emission rate and really met it, the pollution control system would be larger and more costly then the entire cement plant itself. Thus, in his opinion it is not practical. He stated that there is a cement plant in Dade County, Florida (which has regulations based on the LA regulation) that is limited to 40 lbs/hr, but definitely does not meet it. However, he further stated that if any plant was designed to meet an air pollution regulation within the last 4 years, it is probably meeting it.

Mr. Charles Bush, Technical Director of Riverside Cement, in Riverside, California, stated that Riverside County has the same air pollution regulations as Los Angeles County[17]. When questioned as to whether his plant was meeting this regulation he stated that it was. On further questioning, he stated that he felt this regulation was being met most of the time but could not guarantee that it was being met continuously. His control equipment included a 16 compartment glass baghouse with an efficiency above 99.5% for a dry process and an electrostatic precipitator with an efficiency of 99.5% to 99.9% for a wet-process kiln.

All of the cement plant officials and two executives from the Portland Cement Association, Dr. Harry Huntzicker, President and Mr. Ivon LeGore, Safety Director, agree that the most stringent air pollution regulation imposed on cement plants in this country is the Los Angeles County Air Pollution Code or those codes patterned after it. Although there are two basic sections in the Los Angeles Code that affect cement plants; i.e., process-weight basis and gas volume concentration, the most stringent

regulation is the one based on process weight. Mr. Jack Gilliland, Technical Director of Ideal Cement Company, stated that the new regulation in the State of Maryland may be even more stringent than the Los Angeles County Code because it specifies no visible emissions at all.

Since the Los Angeles County Code or other codes based on it are the most stringent regulation for cement plant emissions the section of this Code that applies to particulate emissions, including the process-weight table are included herein. Also, since the San Francisco Bay Area Air Pollution Control District Regulations are the most widely accepted and appear to be more realistic for the Portland Cement Industry, the section of this regulation that applies to particulate emissions is included.

Regulation IV of the St. Louis County Air Pollution Control Code which applies to particulate emissions from industrial processes and is based on the San Francisco Bay Area Code is also included herein to indicate what modifications are typically made when a code is based on another code. It should be noted that the process weight tables and gas concentration tables are identical for the two codes. The Ambient Air Quality Standards for the St. Louis Code are also included to show the maximum dustfall allowable in a given time regardless of the other regulations. The suspended particulate level is also shown.

Other particulate emission codes which are known to be based on the San Francisco Bay Area Code include Gary and Hammond, Indiana, and East Chicago.

The State of Illinois Air Pollution Control Board Regulation for cement kilns states that[18]: "All new cement kilns shall be equipped with gas cleaning devices to reduce the particulate matter in the gas discharged

to the atmosphere to 99.7% of the particulate matter entering the gas cleaning device. However, particulate matter discharged to the atmosphere shall not exceed 0.1 grain per standard cubic foot regardless of the degree of efficiency required by the gas cleaning device." Although the 0.1 grain/SCF is not as restrictive as other codes the requirement for 99.7% collection efficiency is quite stringent.

In regards to air pollution control regulations for cement plants on a worldwide basis, the literature indicates that the Los Angeles County Code is the most stringent regulation in the world today. This is also in agreement with the opinions of the cement plant officials that were consulted during this study.

SAN FRANCISCO BAY AREA, CALIFORNIA

AIR POLLUTION CONTROL DISTRICT

REGULATION 2

(revised 1962)

Division 6, Chapter 1

Section 6111.1 No person shall cause, let, permit, suffer or allow any emission from any general combustion operation or general operation which does not comply with the visible emission limitations in section 3110, Chapter 1, Division 3.

Section 6111.2 No person shall cause, let, permit, suffer, or allow the emission from any general combustion operation of particles in sufficient number to cause annoyance to any other person, which particles are sufficiently large as to be visible as individual particles at the emission point or of such size and nature as to be visible individually as incandescent particles. This section 6111.2 shall only apply if such particles fall on real property other than that of the person responsible for the emission.

Section 6112.1 No person shall cause, let, permit, suffer, or allow the emission from any general operation or general combustion operation of particulate matter from any emission point on a concentration in excess of 0.30 grain per standard dry cubic foot of exhaust gas volume.

Section 6112.2 Except as provided in sections 6112.3 and 6113 no person shall cause, let, permit, suffer, or allow the emission from any general operation or general combustion operation of particulate matter from any emission point at a rate in excess of that specified in Table 2 for the process weight rate allocated to such emission point.

Section 6112.3 The limitations established by section 6112.2 shall not require the reduction of particulate matter concentration, based on the source gas volume, below the concentration specified in Table 3 for such volume; provided that, for the purposes of this section 6112.3, the person responsible for the emission may elect to substitute a volume determined according to the provisions of section 6112.4; and provided further that the burden of showing the source gas volume or other volume substituted therefore, including all of the factors which determine such volume and the methods of determining and computing such volume, shall be on the person seeking to come within the provisions of this section 6112.3.

TABLE 2

ALLOWABLE RATE OF EMISSION BASED ON PROCESS WEIGHT RATE[a,b]

Process Weight Rate		Rate of Emission	Process Weight Rate		Rate of Emission
Lb/Hr	Tons/Hr	Lb/Hr	Lb/Hr	Tons/Hr	Lb/Hr
100	0.05	0.551	16,000	8.00	16.5
200	0.10	0.877	18,000	9.00	17.9
400	0.20	1.40	20,000	10.	19.2
600	0.30	1.83	30,000	15.	25.2
800	0.40	2.22	40,000	20.	30.5
1,000	0.50	2.58	50,000	25.	35.4
1,500	0.75	3.38	60,000	30.	40.0
2,000	1.00	4.10	70,000	35.	41.3
2,500	1.25	4.76	80,000	40.	42.5
3,000	1.50	5.38	90,000	45.	43.6
3,500	1.75	5.96	100,000	50.	44.6
4,000	2.00	6.52	120,000	60.	46.3
5,000	2.50	7.58	140,000	70.	47.8
6,000	3.00	8.56	160,000	80.	49.0
7,000	3.50	9.49	200,000	100.	51.2
8,000	4.00	10.4	1,000,000	500.	69.0
9,000	4.50	11.2	2,000,000	1,000.	77.6
10,000	5.00	12.0	6,000,000	3,000	92.7
12,000	6.00	13.6			

[a] Sections of major importance with reference to this table are sections 2024, 2027, 3213, 3214, and 6112.2.

[b] Interpolation of the data in this table for process weight rates up to 60,000 lb/hr shall be accomplished by use of the equation $E = 4.10P^{0.67}$, and interpolation and extrapolation of the data for process weight rates in excess of 60,000 lb/hr shall be accomplished by use of the equation:

$E = 55.0P^{0.11} - 40$, where E = rate of emission in lb/hr and

P = process weight rate in tons/hr.

Section 6112.4 Any volume of gases passing through and leaving an air pollution abatement operation may be substituted for the source gas volume of the source operation served by such air pollution abatement operation, for the purposes of section 6112.3, provided such air pollution abatement operation emits no more than 40% of the weight of particulate matter entering thereto; and provided further that such substituted volume shall be corrected to standard conditions and to a moisture content no greater than that of any gas stream entering such air pollution abatement operation.

TABLE #3

MINIMUM CONCENTRATION TO BE REQUIRED[a,b]

Source Gas Volume, SCFM	Concentration GR/SCF	Source Gas Volume, SCFM	Concentration GR/SCF
7,000 or less	0.100	140,000	0.038
		160,000	0.036
8,000	0.096	180,000	0.035
9,000	0.092		
10,000	0.089	200,000	0.034
20,000	0.071	300,000	0.030
30,000	0.062	400,000	0.027
40,000	0.057	500,000	0.025
50,000	0.053	600,000	0.024
60,000	0.050	800,000	0.021
80,000	0.045	1,000,000 or more	0.020
100,000	0.042		
120,000	0.040		

[a]Sections of major importance with reference to this table are: Sections 2024, 2030, 6112.3, and 6112.4.

[b]Interpolation of the data in this table shall be based on linear interpolation between adjacent values.

COUNTY OF LOS ANGELES, CALIFORNIA

AIR POLLUTION CONTROL DISTRICT

RULES AND REGULATIONS

REGULATION IV. PROHIBITIONS

(amended June 1, 1965)

Rule 54. DUST AND FUMES. A person shall not discharge in any one hour from any source whatsoever dust or fumes in total quantities in excess of the amount shown in the following table: (see next page)

To use the following table, take the process weight per hour as such is defined in Rule 2(j)*. Then find this figure on the table, opposite which is the maximum number of pounds of contaminants which may be discharged into the atmosphere in any one hour. As an example, if A has a process which emits contaminants into the atmosphere and which process takes 3 hours to complete, he will divide the weight of all materials in the specific process, in this example, 1,500 lbs. by 3 giving a process weight per hour of 500 lbs. The table shows that A may not discharge more than 1.77 lbs. in any one hour during the process. Where the process weight per hour falls between figures in the left hand column, the exact weight of permitted discharge may be interpolated.

This standard is also used by the following jurisdictions:

Providence, Rhode Island
Orange County, California
Sacramento County, California
Florida (entire state)
Sarasota, Florida

---

* Rule 2(j). Process Weight per Hour. "Process Weight" is the total weight of all materials introduced into any specific process which process may cause any discharge into the atmosphere. Solid fuels charged will be considered as part of the process weight, but liquid and gaseous fuels and combustion air will not. "The Process Weight per Hour" will be derived by dividing the total process weight by the number of hours in one complete operation from the beginning of any given process to the completion thereof, excluding any time during which the equipment is idle.

TABLE

Process Wt/hr(lbs)	Maximum Weight Disch/hr(lbs)	Process Wt/hr(lbs)	Maximum Weight Disch/hr(lbs)
50	.24	3400	5.44
100	.46	3500	5.52
150	.66		
200	.85	3600	5.61
250	1.03	3700	5.69
300	1.20	3800	5.77
350	1.35	3900	5.85
400	1.50	4000	5.93
450	1.63		
500	1.77	4100	6.01
		4200	6.08
550	1.89	4300	6.15
600	2.01	4400	6.22
650	2.12	4500	6.30
700	2.24		
750	2.34	4600	6.37
800	2.43	4700	6.45
850	2.53	4800	6.52
900	2.62	4900	6.60
950	2.72	5000	6.67
1000	2.80		
		5500	7.03
1100	2.97	6000	7.37
1200	3.12	6500	7.71
1300	3.26	7000	8.05
1400	3.40	7500	8.39
1500	3.54	8000	8.71
		8500	9.03
1600	3.66	9000	9.36
1700	3.79	9500	9.67
1800	3.91		
1900	4.03	10000	10.0
2000	4.14	11000	10.63
		12000	11.28
2100	4.24	13000	11.89
2200	4.34	14000	12.50
2300	4.44	15000	13.13
2400	4.55		
2500	4.64	16000	13.74
		17000	14.36
2600	4.74	18000	14.97
2700	4.84	19000	15.58
2800	4.92	20000	16.19
2900	5.02	30000	22.22
3000	5.10	40000	28.3
		50000	34.3
3100	5.18	60000	40.0
3200	5.27	or	
3300	5.36	more	

REGULATION IV RESTRICTION OF EMISSION OF PARTICULATE MATTER FROM INDUSTRIAL PROCESSES

A. General Provisions

1. This regulation applies to any operation, process, or activity except the burning of fuel for indirect heating in which the products of combustion do not come into direct contact with process materials and except the burning of refuse and except the processing of salvageable material by burning.

2. Process weight means the total weight of all materials introduced into a source operation, including solid fuels, but excluding liquids and gases used solely as fuels, and excluding air introduced for purposes of combustion.

Process weight rate means a rate established as follows:

a. For continuous or long-run steady-state source operations, the total process weight for the entire period of continuous operation or for a typical portion thereof, divided by the number of hours of such period or portion thereof.

b. For cyclical or batch source operations, the total process weight for a period which covers a complete operation or an integral number of cycles, divided by the hours of actual process operation during such period.

Where the nature of any process or operation or the design of any equipment is such as to permit more than one interpretation of this section, that interpretation which results in the minimum value for allowable emission shall apply.

3. Emission tests relating to this regulation shall be made following the standards in American Society of Mechanical Engineers Power Test Codes PTC - 27 dated 1957 and entitled Determining Dust Concentration in a Gas Stream.

B. Emission Limitations

1. Except as provided for in Section B (2), no person shall cause, suffer, allow, or permit the emission of particulate matter in any one hour from any source in excess of the amount shown in Table 1 for the process weight allocated to such source.

2. The limitations established by Section B (1) shall not require the reduction of particulate matter concentration, based on the source gas volume, below the concentration specified in Table 2 for such volume; provided that, for the purposes of this section the person responsible for the emission may elect to substitute a volume determined according to the provisions of Section B (3); and provided further that the burden of showing the source gas volume or other volume substituted therefor, including all the factors which determine such volume and the methods of determining and computing such volume, shall be on the person seeking to come within the provisions of this Section.

3. Any volume of gases passing through and leaving an air pollution abatement operation may be substituted for the source gas volume of the source operation served by such air pollution abatement operation, for the purposes of Section B (2), provided such air pollution abatement operation emits no more than 40 percent of the weight of particulate matter entering thereto; and provided further that such substituted volume shall be corrected to standard conditions and to a moisture content no greater than that of any gas stream entering such air pollution abatement operation.

4. No person shall cause, suffer, allow, or permit the emission of particulate matter from any source in a concentration in excess of 0.30 grain per standard cubic foot of exhaust gases. If provisions of this subsection would permit a greater emission of particulate matter per hour than allowed by subsection B (1), the provision of this subsection (B-4) shall not apply except that the following regulation shall apply to existing grey iron jobbing cupolas. For purposes of this regulation, a jobbing cupola is defined as a cupola which has a single melting cycle no more than 10 hours in any consecutive 24 hours and no more than 50 hours in any consecutive 7 days.

a. All existing grey iron jobbing cupolas shall be equipped with gas cleaning devices and so operated as to remove 85% by weight of all the particulate matter in the cupola discharge gases, or release not more than 0.4 grain of particulate matter per standard cubic foot of discharge gas, whichever is more stringent.

b. All gases, vapors, and gas entrained effluents from such cupolas shall be incinerated at a temperature not less than 1200° Fahrenheit for a period of not less than 0.3 second.

c. Exception. The following exceptions to the provisions of Regulation IV shall be permitted:

(1) When building a new fire, and

(2) During the start-up, an operational breakdown, or while cleaning air pollution control equipment for any process.

Table 1

Process Weight Rate		Rate of Emission	Process Weight Rate		Rate of Emission
Lb Hr	Tons/Hr	Lb/Hr	Lb Hr	Tons/Hr	Lb/Hr
100	0.05	0.551	16,000	8.00	16.5
200	0.10	0.877	18,000	9.00	17.9
400	0.20	1.40	20,000	10.	19.2
600	0.30	1.83	30,000	15.	25.2
800	0.40	2.22	40,000	20.	30.5
1,000	0.50	2.58	50,000	25.	35.4
1,500	0.75	3.38	60,000	30.	40.0
2,000	1.00	4.10	70,000	35.	41.3
2,500	1.25	4.76	80,000	40.	42.5
3,000	1.50	5.38	90,000	45.	43.6
3,500	1.75	5.96	100,000	50.	44.6
4,000	2.00	6.52	120,000	60.	46.3
5,000	2.50	7.58	140,000	70.	47.8
6,000	3.00	8.56	160,000	80.	49.0
7,000	3.50	9.49	200,000	100.	51.2
8,000	4.00	10.4	1,000,000	500.	69.0
9,000	4.50	11.2	2,000,000	1,000.	77.6
10,000	5.00	12.0	6,000,000	3,000.	92.7
12,000	6.00	13.6			

Interpolation of the data in this table for process weight rates

up to 60,000 lb/hr shall be accomplished by use of the equation $E = 4.10\ P^{0.67}$, and interpolation and extrapolation of the data for process weight rates in excess of 60,000 lb/hr shall be accomplished by use of the equation: $E = 55.0P^{0.11 - .40}$, where E = rate of emission in lb/hr and P = process weight rate in tons/hr.

Table 2

Source Gas Volume, SCFM[a]	Concentration GR/SCF[b]	Souce Gas Volume, SCFM[a]	Concentration GR/SCF[b]
7,000 or less	0.100	140,000	0.038
		160,000	0.036
8,000	0.096	180,000	0.035
9,000	0.092		
		200,000	0.034
10,000	0.089	300,000	0.030
20,000	0.071	400,000	0.027
30,000	0.062		
		500,000	0.025
40,000	0.057	600,000	0.024
50,000	0.053	800,000	0.021
60,000	0.050		
		1,000,000 or more	0.020
80,000	0.045		
100,000	0.042		
120,000	0.040		

[a] Standard cubic foot per minute
[b] Grain per standard cubic foot

AMBIENT AIR QUALITY STANDARDS[a]

Pollutant	Concentration	Remarks
1. Sulfur oxides		
Sulfation	0.25 mg SO_3/100 cm^2 day	maximum annual average
	0.50 mg SO_3/100 cm^2 day	maximum month value
Sulfur dioxide[b]	0.02 ppm	maximum annual average (24-hour sampling time)
	0.10 ppm	24-hour average not to be exceeded over 1 day in any 3-month period
Suspended sulfate (analysis of high-volume filters)	4 micrograms/m^3	allowable maximum annual average
	12 micrograms m^3	not to be exceeded over 1 percent of the time
Sulfuric acid mist	4 micrograms m^3	allowable maximum annual average
	12 micrograms m^3	not to be exceeded over 1 percent of the time
	30 micrograms m^3	hourly average not to be exceeded over 1 percent of the time
2. Hydrogen Sulfide	0.05 ppm	½ hour average not to be exceeded over 2 times per year
	0.03 ppm	½ hour average not to be exceeded over 2 times in any 5 consecutive days
3. Oxidant (total)[c]	0.15 ppm	maximum allowable 1-hour value
4. Dustfall[d e]	10 tons sq mi mo	3-month average above background in all areas except those zoned heavy industrial
	25 tons sq mi mo	3-month average above background in zoned heavy industrial areas
5. Suspended particulates (high-volume sampler)	75 micrograms/m^3	annual geometric mean
	200 micrograms m^3	annual 99th percentile
6. Soiling index	0.4 Coh per 1,000 lineal feet	annual geometric mean

[a] All standards, unless otherwise indicated, refer to places where people live or an undesirable effect could result from levels above the standard.

[b] By West-Gaeke or conductometric methods.

[c] Potassium iodide colorimetric method of measurement.

[d] Use background value of 5.0 tons/sq mi/mo in all areas.

[e] Total dustfall including water soluble and water insoluble and all other components.

6.0 CONTROL TECHNOLOGY

There are three basic types of equipment that are used for collecting dust. These are the dry mechanical collectors, or more specifically cyclones, electrostatic precipitators, and fabric filters or baghouses. All have widespread use in the Portland Cement Industry and will be discussed in detail.

6.1 Cyclones

Cyclones are the least efficient of the three types of equipment and must be followed by one of the other types of equipment if stringent air pollution regulations are to be met by cement plants. On dusts that are not too fine efficiencies of 80% can be obtained but for very fine dusts efficiency can drop to as low as 60%.[6] Collection efficiency usually drops off when particle sizes reach the range of 20 to 40 microns and since 80 to 90 percent of the finished cement is less than 75 microns and more than 95% is less than 45 microns, the cyclone is not too practical for the finishing operations. However, for clinker emissions which may be as large as 600 to 900 microns, the cyclone is quite efficient. Advantages of cyclones are that they are fairly cheap, do not break down, have moderate pressure drop across them, and require little servicing.

For the dry-process kilns discussed in the previous section, only two had multicyclones for dust collection. One system had a collection efficiency of 86.9% and emitted 9,390 lbs/day of dust to the atmosphere and the other had an efficiency of only 70.2% and emitted 76,900 lbs/day of dust to the atmosphere.[5] Six of these plants had multicyclones followed by electrostatic precipitators. The cyclone efficiencies were 60% to 77.7% while the overall efficiency after the precipitator varied from 91.9% 5o 96.8%. This arrangement of scalping the larger particles by use

of cyclones ahead of baghouses or ahead of electrostatic precipitators has proven very satisfactory in the cement industry. In fact, demonstrations in the industry have shown that a draught fan will not last many months when it is placed on the dirty-gas side or ahead of multicyclones because abrasions causes very rapid wearing away of fan vanes and scrolls.[1]

For the 22 wet-process kilns discussed in Reference 5, only two had multicyclones and both were followed by electrostatic precipitators.

6.2 Electrostatic Precipitators

There are two basic types of electrostatic precipitators, plate and pipe.[19] The pipe type precipitator is used mainly for removal of liquid or sludge particle and volatilized fumes and thus is not of interest in cement plants. The plate type, however, is used primarily for dry dust removal and will be the type discussed here.

In electrostatic precipitators the gases pass between electrodes at a high difference of potential (50 kV).[6] The grounded collecting electrodes are a series of parallel plates encased in a shell, with the discharge electrodes suspended between these plates by means of insulators connected to the high voltage source. A corona discharge is maintained between the electrodes and when the gases containing suspended particles passes through this field, the particles become charged, usually negatively. These charged particles are then attracted to opposite (positive) charged electrode and become deposited on it.

The particles must then be removed from this electrode. This is accomplished by vibrating or rapping these electrodes at intervals causing the caked dust to fall to the bottom of the chamber where it is removed for disposal or return to the process. Sometimes the precipitation may be cleaned by washing.

Many variables such as gas velocity, density and composition, dust quantity, resistivity, moisture, treatment time, efficiency requirements, etc., affect the size and design of a precipitator. Because of these criteria, precipitator manufacturers do not usually agree on designs. In fact, in a series of ten precipitator designs which were bid by five different manufacturers, all designed to handle one process and to meet the same efficiency, the range of basic design parameters was disheartening.[20] The parameters compared included the power, the treatment time, the gas velocity and the cost. The variation in these factors was so great that no agreement on proper collection configuration could be made. Table 3 lists the 4 basic criteria and has the most conservative as 100 percent and the other bids as a percentage of this maximum value.

Table 3. Comparison of Basic Criteria for Electrostatic Precipitator Designed for One Chemical Process[20]

Manufacturer	Power	Time	Velocity	Price	Average
A. Plan 1	89.6	88.7	86.4	96.0	90.2
A. Plan 2	100.0	100.0	100.0	100.0	100.0
A. Plan 3	98.8	69.6	82.1	87.2	84.4
B. Plan 1	63.3	57.8	64.8	62.1	63.5
B. Plan 2	59.2	52.7	62.1	62.6	59.2
B. Plan 3	55.5	29.1	50.0	34.4	42.2
C. Plan 1	58.0	51.7	61.3	64.6	58.9
C. Plan 2	42.0	40.3	61.3	38.8	48.1
D.	52.6	42.9	64.4	32.7	48.2
E.	52.6	32.2	53.8	27.2	43.9

One basic advantage of the precipatator is its ability to handle large volumes of gas with very little pressure drop and thus low power requirements because the force of the precipitator is applied only to the particles to be collected. A precipitator can also handle high temperature gases and corrosines if necessary.

There are also many problems associated with electrostatic precipitators in operations such as a cement plant where it is necessary to operate kilns on a continuous basis, around the clock, every day of the year. This is true not only from a maintenance and repair standpoint but also because of shortcomings inherent in the design of the precipitator. Mr. Doherty, Director of Lehigh Valley Air Pollution Control District, states that a common expression used by cement-plant management is that you can spend a million dollars on electrostatic precipitator equipment and not do the job you intended to do.[1]

When electrostatic precipitators were first installed in the industry in 1933, the following problems arose:[6]

1. Cement kiln exit gases contain oxides of sulphur which corrode the metal parts creating leakage paths for the current with subsequent voltage drops and efficiency drops.
2. Dust deposited on insulators formed leakage paths with cosequent reductions in efficiency.
3. Condensation was the chief problem and was due to inleaking air. A fan was added but dust caused abrasion, unbalancing the fan. Accordingly, the fan was removed but with careful attention paid to inleaks.
4. Sulphur acids also diffused into the concrete casing and eventually destroyed it. Changing from a 60% lime cement lining the casing with acid-resisting brick set in acid-resisting cement.
5. Unless careful screening is used electrostatic precipitators can cause serious radio and worse TV interference.

Many years' experience has helped precipitator manufacturers improve the efficiency of their equipment to the point that when new precipitators are installed, their efficiency is adequate. The cement industry, however, still has problems of decreasing efficiency with age. The sulfide and sulfate problem is still apparent. Alkalies form a dense shell or coating on high-voltage components. Arcing and burning of filaments frequently cause short circuits which require shutting a section down for repairs. When this happens the exit gases are dumped directly to the atmosphere with no control. If this is to be avoided the kiln must be shut down and production lost. There is considerable amount of arcing and sparking inside a precipitator. When cold kilns are started up again, it is necessary to bypass the electrostatic precipitator for periods up to 24 hours due to the danger of explosion caused by the presence of combustible gas or coal dust. Thus, for a period of 24 hours there is no kiln dust control. One precipitator explosion in the Lehigh Valley in Pennsylvania resulted in damage of $48,000 during the first few hours of kiln startup.[1]

Mr. Kester[20] quotes from a 1969 report to the Missouri Air Conservation Commission on Cement Plant Emissions which states that if a hypothetical precipitator were designed for 99.0 percent efficiency and had an acceptance test of 99.4%, in one or two-years the unit could be "tuned" to an efficiency of 99.1-99.3% but the day-to-day running efficiency would be 96-98%.

Mr. Doherty[1] states that attainment of a smooth and uninterrupted dust collection system with an electrostatic precipitator in a Lehigh Valley cement plant would require that all such units should be followed by an identical precipitator or be followed by a fiberglass baghouse filter.

In spite of all the problems associated with electrostatic precipitators, however, these units have widespread use in cement plants, particularly for wet-process plants. Of the 22 wet-process plants analyzed in Reference 5, 21 had electrostatic precipitators with efficiencies ranging from 92.4% to 99.5% with the majority being above 99%.

For a 99% efficient unit the cost of materials for a precipitator may be only $1.00/cfm of gas.[19] However, a complete turnkey job may amount to over $5.00/cfm gas on an erected basis.[19] The additional electrostatic precipitator that Missouri Portland Cement Plant installed recently on its kiln No. 1 to meet the St. Louis County Air Pollution Code was a $700,000 unit.

6.3 Glass-Fabric Baghouses

One of the oldest means of removing particulates from air or gas streams has been collecting devices based on fabric. Fabric filters are quite efficient, are reliable and can remove particulate matter ranging from 2 microns and larger to less than 0.5 micron.[20]

Fabric filter systems may be divided into the way they are cleaned; i.e., intermittent, periodic, and continual. Intermittent type collectors have fabric bags that must be shut down regularly to remove dust cake. These are limited to processes that can be shut down readily, such as for lunch, and returned to service. They, of course, cannot be used in cement plants which are run continuously. The periodically cleaned collector is a series of intermittent types connected so that specific sections can be shut down at predetermined times, cleaned, and returned to service. In the continual type system, tensioning of the bags to perhaps 50 to 100 lbs. permits better cleaning, which in turn requires fewer reverse air cycles.[1]

This practice has resulted in longer bag life and thus lower overall expenses.

The simplicity of design and operation of the baghouse system, which results in lower costs, is offset somewhat by an increased fan-power requirement to offset the large pressure drop in the baghouse. Many baghouses operate with a 3- to 7-inch drop in water gauge because of the pressure drop through ducting, valves, and bag fabrics.[1] Fan horsepower may vary from 250 to 600 H.P. and up to 25 inches static pressure.[1] Although the original cost of a baghouse is generally less than the cost of an equivalent electrostatic precipitator, or particularly where very high efficiencies are required by law, the higher power costs of operating the fans may offset this cost advantage.

Baghouses of course also have some disadvantages or some areas where caution must be used. Thes include:[19]

1. Dryers and kilns that discharge gas with high water-vapor content. In general, glass bag collectors are not recommended on large gas volume wet-process installations and are not highly recommended in cold climate.[20]
2. Extremely hygroscopic or deliquescent dusts may present problems.
3. Gas-stream temperatures are limited to less than 600°F.

Although the moisture content is listed as a problem area and electrostatic precipitators are generally recommended for wet-process cement plants, there are some wet-process plants that have had extremely good service from a baghouse. Mr. Doherty[2] states that bag life is determined largely by temperature. For operations with temperatures less than 400°F,

he states that bag life may be up to 10 years, whereas for 600°F the bag life may not be over 1 year. He further states that the Penn-Dixie No. 4 Plant at Nazareth, Pennsylvania installed a baghouse containing 950 bags in 1964. Many of the original bags are still in operation which means a bag life of at least 6 years. The major problem experienced at this plant has been mechanical injury of the bags caused by condensation and crystallization. The bags on the north side of this particular plant have much more of a condensation problem which has resulted in shorter bag life on the order of 3 to 4 years. Mr. Charles Bush[17] stated that average life of their bags at Riverside Cement Plant in California was 2 to 3 years with moisture reducing the life.

Mr. Kester[12] stated if high alkali raw materials are used, glass bags deteriorate rapidly and develop holes. The first place for the bag to fail was stated to be the cup of the bag which is the area where condensation generally causes the problem.

When a glass bag breaks in an upward flow baghouse, it can be tied off with fiberglass rope in a few seconds and the baghouse put back into service immediately until a new bag may be installed. This is a definite advantage over a short-circuited electrostatic precipitator. Mr. Bush stated that their baghouse has 16 compartments with 15 compartments being used continuously and 1 compartment always down for routine maintenance or to repair bags.[17] He stated that the collection efficiency of this system was above 99.5 percent and that nothing visible was emitted to the atmosphere.

In general most of the cement plant officials and other people knowledgeable in this area feel that the glass-fabric baghouse should be

the choice for collecting dry-process kiln gases and electrostatic precipitators should be the choice for wet-process kilns. However, they further state that a higher collection efficiency can be maintained with the baghouse than with the precipitators.

Some plants where baghouses have been used successfully are the Riverside plant in Riverside, California, at American Cement Company's plant at Oro Grande, California, at Universal Atlas Cement Company's plant in the Lehigh Valley and at the Penn-Dixie No. 4 Plant in Nazareth. Pennsylvania. The Hercules Cement Company Plant at Stockertown, Pennsylvania installed a baghouse in 1958-1959 that was the best in the country at that time.[21] However, they are presently in the process of updating this system by adding a $1,000,000 baghouse.[2]

The baghouse used by Universal Atlas Cement Company contains 2000 bags and cost approximately $2,000,000.[2] The Whitehall Cement Company at Whitehall, Pennsylvania is presently replacing an electrostatic precipitator with a 99.9% efficient baghouse at a cost of approximately $750,000.[2] They were told by the company that will install the baghouse that it will take 42 weeks to install it because of the backlog of work at the present time.

In the Lehigh Valley, 8 plants had baghouses on some kilns or all kilns by 1966.[1] These systems included more than 8,000 fiberglass bags and with the additions of bags discussed in the preceding paragraph there are probably more than 10,000 bags in service in that area at the present time.

7.0 DESCRIPTION OF PLANT UTILIZING BEST TECHNOLOGY

Mr. Bruce Kester of Missouri Portland Cement Company is recognized by all of the cement plant officials and the Portland Cement Association executives as one of the most knowledgeable men in the world on the subject of air pollution control in the cement industry. He indicated that he had visited most of the cement plants in this country, in Mexico, and in Canada, and had visited plants in Europe and Asia Minor. Without hesitation, when asked which plant in the world was the best controlled from an air pollution viewpoint, Mr. Kester stated that the Ideal Cement Plant in Seattle, Washington, has the best overall dust control. Dr. Huntzicker and Mr. LeGore of the Portland Cement Association agreed with this statement and so have other industry representatives that are familiar with this plant.

The following description of the Ideal Cement Company Plant in Seattle was obtained from discussions with Mr. J. L. Gilliland, Technical Director of Ideal Cement Company who is located in their office in Denver, Colorado,[15] from an Ideal Cement Company Brochure on the formal dedication of the Seattle Plant on August 23, 1967,[10] and from a paper that describes the plant in detail.[22] A general description followed by a more detailed description dust handling equipment will be given.

The Ideal Cement Plant in Seattle is a 2 1/2 million barrel wet-process system. The compactness of the plant which was made necessary by the 25-acre site turned out to be an advantage in control, operation, accessibility, maintenance and first cost.

The plant is fully automated, i.e. operated with complete computer control for all operations except unloading; load-out, and packhouse operations. A direct digital computer controls raw material blending and grinding, kiln burning and cooling, and finish grinding. An x-ray analyzer in the control room provides instant analysis of all materials in the raw material and clinker which gives better quality control and a better product. This computer control has surpassed all expectations of the company's technicians in the approximately three years the plant has been in operation.

Problems involved in design and construction of the plant included unstable soil common to the waterfront area and designing for earthquake resistance. More than 2,900 prestressed, precast 14" octagonal pilings from 50' to 160' in length -- about 55 miles in total length -- with a load-bearing capacity of 150 tons each-support major equipment and structures on heavy foundations. About 4,000 tons of sheet steel piling and more than 120,000 cu. yd. of concrete were used in the plant construction.

Cleanliness of the plant was factor in selecting the precast wall panels and roof slabs. Other efforts for cleanliness included installation of 54 dust collectors -- at every conceivable dust point, 3 complete vacuuming systems, troughs and drag-chain conveyors under belt conveyors to collect spillage, etc.

Pre-crushed limestone, sand, clay and slag are delivered to the plant by barge while gypsum comes by rail. By receiving these raw materials from other locations, one source of air pollution is inherently avoided

at this plant, that of quarrying and initial crushing. The limestone is received at the dock in less than 1 1/2" size.

All raw materials are unloaded by a traveling crane with a 7 cu. yd. clamshell bucket. Unloaded onto a conveyor belt the raw materials are carried to storage areas. From the storage area different types of conveyor systems are used to discharge the various materials in the proportions required for blending.

7.1 Raw-Feed Blending

Initial grinding is done in this plant by a single ball mill in closed circuit with screens. Silica sand is pre-ground in a smaller mill to assure proper blending with other raw materials except when Type I cement is being made when it goes directly to the raw mill. The silica and mill is a 6'7" x 14' grate discharge ball mill that is loaded with 25 tons of 2" and 1 1/4" steel balls. It grinds 25 tph to a fineness of 60% through 200 mesh.

The other raw materials generally go directly to the raw mill which is a 2-compartment 11' x 36' F. L. Smidth wet-grinding raw mill. This mill is loaded with 135 tons of CFJI steel balls, with 3" and some 4" in the first compartment, and 2" and 1 1/4" in the second. The mill operates in closed circuit with three 18" Dorr-Oliver DSM screens with 0.6 mm openings. The output averages 640 bbl. per hr. with 99% passing a 50-mesh screen, and 85% passing 200 mesh.

The finished slurry goes to three 50-ft. dia., 8,000 bbl covered concrete kiln feed tanks. These tanks hold enough slurry for 72 hours of

kiln operation. Normally one tank is being filled while another is mixing and the third is supplying kiln feed.

7.2 Kiln and Cooler Control

The 15'6" x 14' x 500' Allis-Chalmers kiln is rated at 7,200 bbl. per day capacity. Exit gases are drawn at about 600°F into a Buell SF Model 23 GA electrostatic precipitator, which is rated at 400,000 cfm at 700°F. This precipitator consists of two parallel sections, each with three compartments. The draft fan, a 400,000 cfm Sturtevant unit driven by a 600-hp motor, is preceded by automatic dampers and exhausts 99.4% dust free gases through a 250' Kellogg reinforced concrete stack. An automatic safety cutoff for the precipitator eliminates any possibility of explosions.

Dust is collected in six hoppers under the precipitator and is removed by six pneumatic systems to a pair of 11,000 cu. ft. dust bins, or to waste. One bin usually gets the dust from the first two precipitator compartments which is weighed out and returned to the kiln for insufflation at up to 21 tph. The higher alkali dust from the second pair, about 10% of the total dust, can be leached in a pair of dual rake classifiers. The leached classifier product is pumped to the kiln feed pipe at any desired rate. The overflow from the classifiers is neutralized to a required pH, and cleared, before being pumped to the sewage system. The dust from the last precipitator compartments is sometimes trucked to waste, using a dustless loader with sprays.

The clinker is discharged from the kiln to a 2-section, horizontal-grate air-quenching clinker cooler. This cooler has two grate sections

with a 30" x 126" reversible clinker breaker. Discharge is by two 12" drag chains. Clinker temperature at discharge is 100-110°F.

7.3 Clinker Handling and Storage

The clinker is discharged from the cooler to a 24" drag-chain conveyor which, in turn, discharges to a pair of 24" transverse drag chains which are the first units in a dual handling system between the kiln and the mills, to insure against any breakdowns. Clinkers are usually discharged by conveyor to the mill feed bins for final grinding.

7.4 Finish Grinding

Clinker which is stored in 28,000 cu. ft. silos is discharged by conveyors. Gypsum from 27,000 cu. ft. silos is added to the mill feed belt. Dry additives are added by feeders, and liquid additives are added by built-in feeders.

The two 12' x 32' finish grinding mills are loaded with 175 tons of CFJI 3", 2", and 1 1/4" steel balls. Each mill operates in closed circuit with an 18' Raymond centrifugal, double-whizzer separator, which receives the mill output by a conveyor. The separator rejects are returned to the mill by another air conveyor. Grinding is done to a fineness of 90% through 325 mesh--105,625 openings to the square inch.

The finished cement goes to vertical cement coolers and from there to storage.

7.5 Storage-Packing-Loading

The cement storage facilities consists of 26 silos and 2 interstices with an unusually large total capacity of 373,000 bbl of cement which is

well located for efficient loading out and delivery of bulk or bagged cement by truck, rail or water.

7.6 Dust Collection, Miscellaneous

The plant has 53 dust collectors and a kiln precipitator, installed at a cost of more than $4 million and located at every conceivable dust source which is evident in the cleanliness of the plant and its surroundings. (The total plant investment was approximately $30 million.) Thirty-seven of the dust collectors are Pulverizing Machinery-Slick Industrial Co. Mikro-Pulsaire collectors that are fully automatic and self-cleaning. Periodic cleaning of the filter cylinders is accomplished by a momentary jet of high-pressure air at each cylinder.

Two of the 53 collectors are said to be the first bag collectors ever used for venting the second stage of a clinker cooler. (Recently the Kaiser Cement and Gypsum's Permanente, California plant, the West's largest, installed a $1.1 million baghouse system on clinker coolers and is believed to be the first to utilize baghouses connected by a manifold duct system to several coolers. This system was designed with a collection efficiency in excess of 99.9% which virtually eliminates all particulate emissions from clinker cooler exhaust air).[23] The Seattle clinker cooler bags use DuPont Nomex nylon fabric, which is a 16-ounce felt making possible a 7.8 to 1 air-to-cloth ratio. This cloth is continually exposed to temperatures of 275°F, with surges to 375°F, and is expected to last over 30 months. A damper diverts to the stack if temperature exceeds 475°F. A common 125,000-cfm fan is connected to these two collectors.

Other Mikro-Pulsaire bag collectors that range from 2,070 to 36,000 cfm are installed at the gypsum and raw material unloading and handling systems, the raw and clinker silo feeds, the clinker conveyor system, finish mill department, sepatator exhaust (four 36,000 cfm units), cement storage silos, bulk loading stations, and the new packhouse. Dust collectors also clean the air going into the eight electrical rooms and to the compressor room.

For cleanup, there are three Lamson stationary vacuum cleaning systems--in the mill building, in the cooler building and the laboratory area of the main building, and in the new packhouse. There are also two power vacuum sweepers, which keep driveways and other areas clean.

Belt conveyors, with 35° idlers, are used whenever possible and have driffle drag cleanup and hopper bottoms for feed to the dust collectors.

REFERENCES

1. Doherty, R. Emmet. Current Status and Future Prospects - Cement Mill Air Pollution Control. Presented at the Third National Conference on Air Pollution, Washington, D.C. December 12-14, 1966.

2. Personal communication with Mr. R. Emmet Doherty, Director Lehigh Valley Air Pollution Control, Northampton, Pennsylvania. September 10, 1970.

3. Trauffer, Walter E. Cement 1969-1970. Pit and Quarry, pp. 86-99. January, 1970.

4. Trauffer, Walter E. Cement Industry Progress. Pit and Quarry, p. 73, July, 1970.

5. Kreichelt, Thomas E., Kemnitz, Douglas A., and Stanley T. Cuffe. Atmospheric Emissions from the Manufacture of Portland Cement. Public Health Publication No. 999-AP-17. U.S. Department of Health, Education, and Welfare, Public Health Service, Bureau of Disease Prevention and Environmental Control, Cincinnati, Ohio. 1967.

6. Burke, E. Dust Control in the Cement Industry. Cement Lime and Gravel, pp. 317-322. November, 1969.

7. Cement. Encyclopedia Americana, Vol. 6, pp. 188-191. Copyright 1959.

8. Cement. Encyclopedia Britannica, Vol. 5, pp. 154-157. Copyright 1969.

9. A New Cement Works in Missouri. Cement Lime and Gravel, pp. 206-208. July 1969.

10. Introducing Ideal Cement Company's Plant at Seattle, Washington. Company Brochure from Formal Dedication of Ideal Cement Company's Seattle Plant, August 23, 1967.

11. National Emission Standards Study. Report of the Secretary of Health, Education, and Welfare to the United States Congress in Compliance with Public Law 90-148 The Air Quality Act of 1967. Document No. 91-63. March, 1970.

12. Personal communication with Mr. Bruce E. Kester, Director of Research, Missouri Portland Cement Company, St. Louis, Missouri. August 31, 1970 and September 10, 1970.

13. Kannewarf, A. S., and C. E. Clausen. What Do You Know About Cement Kilns? Rock Products May 1962.

14. Stumph, Terry L., and Robert L. Duprey. Trends in Air Pollution Control Regulations, Part 3. Environmental Control Management, pp. 42-44. December, 1969.

15. Personal communication with Mr. J. L. Gilliland, Technical Director, Ideal Cement Company, Denver, Colorado. September 4, 1970.

16. Personal communication with cement plant officials and executives of the Portland Cement Association. September, 1970.

17. Personal communication with Mr. Charles Bush, Technical Director, Riverside Division of American Cement Corp., Riverside, California. September 10, 1970.

18. A Compilation of Selected Air Pollution Emission Control Regulations and Ordinances. Public Health Service Publication No. 999-AP-43. U.S. Department of Health, Education, and Welfare, Public Health Service, Bureau of Disease Prevention and Environmental Control, National Center for Air Pollution Control. Washington, D.C. 20201. Revised Edition. 1968.

19. Section IV Air Pollution Control. Basic Technology. Chemical Engineering Deskbook Issue, pp. 165-172. April 27, 1970.

20. Kester, Bruce E. Air Pollution-Rule and Regulation. IEEE Transactions on Industry and General Applications, Vol. IGA-5, No. 3, pp. 237-241. May/June 1970.

21. Personal communication with Mr. Ladd Parsons, Hercules Cement Company, Stockertown, Pennsylvania. September 10, 1970.

22. Trauffer, Walter E. Ideal's Seattle Plant. Pit and Quarry, pp. 108-119, July, 1969.

23. Twenty Baghouses on Clinker Coolers for Permanente Cement Plant. Pit and Quarry, p. 133. July 1970.